METEOROLOGICAL MONITORING, DISPERSION OF RADIOACTIVE EFFLUENT INTO THE ATMOSPHERE AND POPULATION RISK ANALYSIS *)

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Abstrak

PEMANTAUAN METEOROLOGI, DISPERSI EFLUEN RADIOAKTIF MELALUI ATMOSFER DAN ANALISIS RISIKO TERHADAP PENDUDUK. Meteorologi adalah salah satu faktor penting dalam tahapan pemilihan tapak fasilitas nuklir. Untuk memprediksi pola penyebaran radioaktif di udara dalam jangka panjang dan operasi normal dapat digunakan metode TIC (*Time Integrated Concentration*). Perhitungan dosis inhalasi I-131 dapat digunakan model sederhana yang direkomendasikan Clark. Data yang digunakan dalam simulasi adalah data meteorologi sekunder hasil pemantauan Newjec dari bulan Agustus 1994 sampai dengan Juli 1995. Perhitungan dosis ekivalen efektif dilakukan dengan asumsi untuk PWR 900 dengan Q_0=3.7.10^{11} Bq/tahun. Nilai TIC/Q tertinggi adalah 52.92 s^2m^{-3} yang terjadi pada arah NNW dan radius 200 meter dari titik lepasan. Nilai TIC/Q mula-mula naik dan mencapai puncak pada jarak 200 meter kemudian turun secara asimptotis untuk semua sektor. Nilai tertinggi dosis ekivalen efektif terjadi pada sektor NNW jarak 200 m, yaitu 1.74e-03 mSv/tahun.

Abstract

METEOROLOGICAL MONITORING, DISPERSION OF RADIOACTIVE EFFLUENT INTO THE ATMOSPHERE AND POPULATION RISK ANALYSIS. Meteorology is one of the factors which shall be considered at survey stage for site selection of nuclear facility. Prediction of radionuclide concentration at atmosphere for long-term and normal release can be conducted by Time Integrated Concentration method. Calculation of inhalation dose of I-131 can be applied by simple model that was recommended by Clark. The data needed for simulation are meteorology secondary data as a result of meteorological monitoring for one year duration started from August 1994 up to July 1995. Calculation of effective dose equivalent is established by assuming PWR 900 type with Q_0=3.7.10^{11} Bq/year. The highest TIC/Q value of 52.92 s^2m^{-3} occurred at NNW sector and 200 meter radius from release point. TIC/Q increases with radii for all sectors and reach its peak value at about 200-300 meter from release point. TIC/Q then go down and curves will reach some asymptotes.The highest of effective dose equivalent is happened at NNW sector 200 m distance of 1.74e-03 mSv/year.

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I. INTRODUCTION

In the nuclear reactor, radionuclides are formed as a result of fission reaction. Activation of structure matter of reactor and impurity existence of cooling water also can result radionuclides. Almost all of radionuclides as a result of fission product remain in the fuel matrix as long as there is no rupture of fuel cladding. Unfortunately, radionuclides gas (e.g., xenon, krypton) can escape from the fuel matrix and then spread to the environment. Before radionuclides gas or particulate released to the environment, they must be treated by scrubbing or gas adsorption for fulfilling the regulation of radionuclides emission. The treated effluent then to be released to the atmosphere through the stack. The effluent are dispersed into the atmosphere as soon as being released from the stack. Therefore, the atmosphere is an important pathway for the transport of radioactive releases from a nuclear power plant to the environment and thereby to man.

The atmospheric dispersion of radionuclides effluent are affected by following factors:

1. Velocity of exiting gas
2. Height of stack
3. Atmospheric condition such as atmospheric stability, rainfall and windrose.
4. Topography

Meteorology is one of the factors which shall be considered at survey stage for site selection. The meteorological characteristics of a site, when considered with other factors such as population density and land use in the region, are in many cases an important element in determining the suitability of the site.

Risk of population caused by both internal and external radiation dose depend on the pattern of radionuclides dispersion into the atmosphere as well as distribution of population around the site. The relationship between meteorological monitoring and risk analysis of population caused by radionuclides dispersion can be seen at figure 1.

It has been customary in the safety analysis of nuclear power plants to prepare dispersion estimates with different degrees of emphasis and various accuracy requirements at the stages of (a) site survey, (b) site evaluation, and (c) operation of the plant, and for accident contingency planning. But, in this paper we do not discuss dispersion for accident contingency planning.

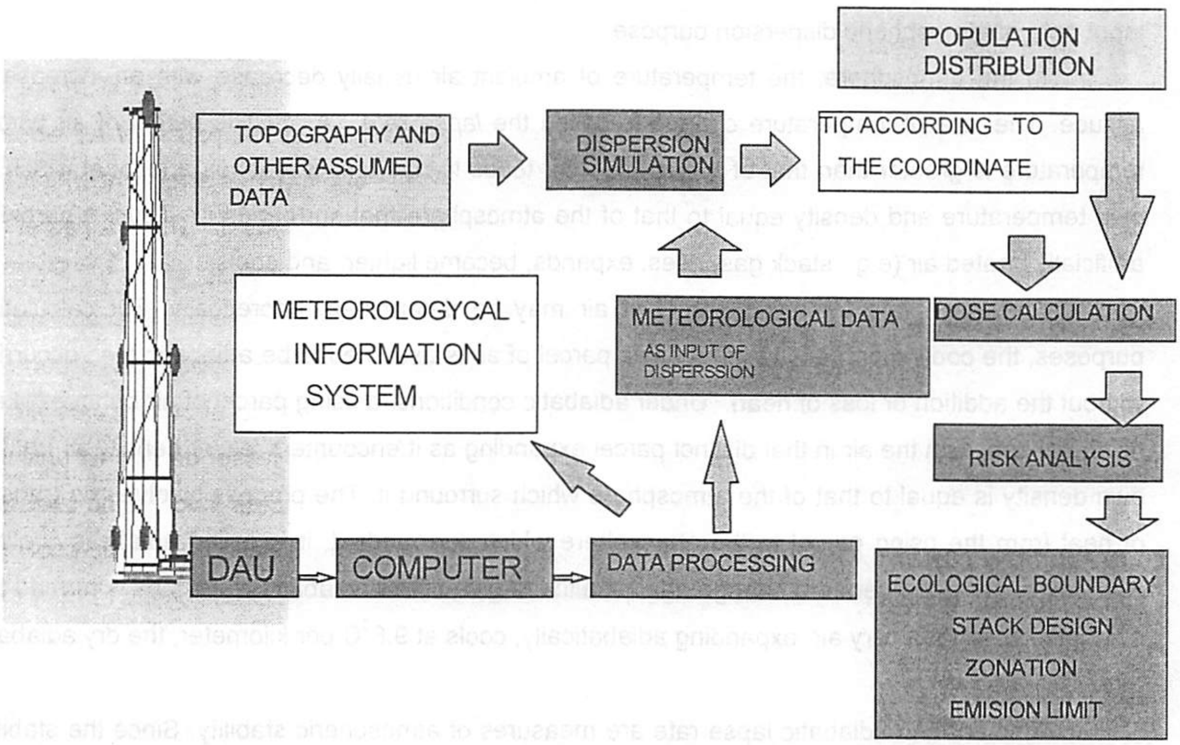

Figure 1. Diagram of Meteorological Monitoring and Risk Analysis of Nuclear Facility Caused by Atmospheric Dispersion of Radionuclides

II. THEORY

Pollution problems arise from confluence of atmospheric contaminants adverse meteorological condition, and, at times, certain topographical conditions. Because of the close relationship that exist between air pollution and certain atmospheric conditions, it is necessary for the environmental engineer to have a thorough understanding of meteorology. Data collecting of meteorological parameter must be conducted by continue monitoring around the site. Meteorological data processing is significant to support comprehensive environmental information system as well as to support data input of atmospheric dispersion simulation.

Meteorological data collecting cover temperature (2 height level or more), wind speed and direction (2 height level), rainfall, relative humidity and solar & net radiation. Meteorological monitoring system of Ujung Lemahabang station apply the Automatic Weather Station (AWS). Data Acquisition Unit (DAU) is used to save the data of sensor signal for certain period. Its capacity depends on total data memory transferred and the period of sample download. The meteorological data from DAU then transferred to the computer (laptop) and saved within certain file name (row data). The row data within one file are still mixed and include more than one parameter. The row data is processed by a computer program (still being developed) to separate each parameter and each month period. The data output need further processing for both information system and for input data of atmospheric dispersion purpose.

In the atmosphere, the temperature of ambient air usually decrease with an increase in altitude. The rate of temperature change is called the *lapse rate*. A specific parcel of air whose temperature is greater than that of the ambient air tends to rise until it reaches a level at which its own temperature and density equal to that of the atmosphere that surrounds it. Thus, a parcel of artificially heated air (e.g., stack gas) rises, expands, become lighter, and cools.

The lapse rate for rising parcel of air may be determined theoretically. For calculation purposes, the cooling process within a rising parcel of air is assumed to be adiabatic (i.e., occurring without the addition or loss of heat). Under adiabatic conditions, a rising parcel of air behaves like a rising balloon, with the air in that distinct parcel expanding as it encounters lesser density air until its own density is equal to that of the atmosphere which surround it. The process involves no transfer of heat from the rising parcel to the atmosphere which surrounds it, it is called adiabatic cooling. Ratio expressing temperature change against altitude gain under adiabatic conditions is termed the adiabatic lapse rate. Dry air, expanding adiabatically, cools at 9.8^{0}C per kilometer, the dry adiabatic rate.

Ambient and adiabatic lapse rate are measures of atmospheric stability. Since the stability of air reflect the susceptibility of rising air parcels to vertical motion, consideration of atmospheric stability or instability is essential in establishing the dispersion rate of pollutants. The atmosphere is said to be unstable as long as a rising parcel of air remains warmer (or descending parcel remain cooler) than the surrounding air, since such a parcel will continue to accelerate in the direction of the displacement. Conversely, when a rising parcel of air arrives at an altitude in a colder and denser state than the surrounding air, the resultant downward buoyancy force pushes the displaced parcel of air earthward and away from the direction of displacement. Under such conditions, the atmosphere is said to be stable.

Stability is a function of vertical distribution of atmospheric temperature, and plotting the ambient lapse rate against the adiabatic lapse rate can give an indication of the stability of the atmosphere.

When the ambient lapse rate exceeds the adiabatic lapse rate, the ambient lapse rate is said to be superadiabatic, and the atmosphere is highly unstable. When the two lapse rate are exactly equal, the atmosphere is said to be neutral. When the ambient lapse rate is less then the dry adiabatic lapse rate, the ambient lapse rate is termed subadiabatic, and the atmosphere is stable. If temperature is constant throughout a layer of atmosphere, the ambient lapse rate is zero, and atmosphere layer is describe as isothermal, and the atmosphere is stable.

Temperature of ambient air increases, rather than decreases, with altitude, the lapse rate is negative, or inverted, for the normal state. Negative lapse rate occurs under conditions commonly referred to as an inversion, a state in which warmer air blankets colder air. Thermal or temperature inversion represent high degree of atmospheric stability.

By comparing the ambient lapse rate to the adiabatic lapse rate, it may be possible to predict what will happen to gases emitted from a stack. When the ambient lapse rate is superadiabatic (greater than the adiabatic) the turbulence of the air itself causes the atmosphere to serve as an effective vehicle dispersion. In this highly unstable atmosphere, the stream of emitted pollutant undergoes rapid mixing, and any wind causes large eddies which may carry the entire plume down to the ground, causing the concentrations close to the stack before the dispersion is complete.

The ambient lapse rate is equal to or very near the dry adiabatic lapse rate, the plume issuing from single smokestack tends to rise directly into the atmosphere until it reaches air density similar to that of the plume itself. This type emission called neutral plume.

The ambient lapse rate is subadiabatic (less than the dry adiabatic), the atmosphere is slightly stable. Under such conditions, there is limited vertical mixing, and the probability of air pollution problems in the area is increased. The typical plume in such conditions is said to be "coning".

The lapse rate is negative, as in the presence of an inversion, the dispersion of stack gas is minimal, because of lack of turbulence. In the extremely stable air, a plume spread horizontally, with little vertical mixing, and is said to be "fanning". In the area where radiation inversions are common, construction of stack high enough to allow for discharge of emissions above the inversion layer is recommended.

The lapse rate is superadiabatic above the emission source and inversion conditions exist bellow the source, the plume is said to be lofting. A lofting plume has minimal downward mixing, and the pollutants are dispersed downwind without any significant ground-level-concentrations.

The inversion layer a short distance above the plume source and superadiabatic conditions prevail below the stack, the plume is said to be "fumigating". Fumigating often begin when a fanning plume breaks up into a looping plume, as when morning sun breaks up a radiation inversion and the superadiabatic conditions below the inversion act to move the plume into a vigorously looping pattern.

Similar to the conditions which provoke the :fumigating" plume are the conditions which create a "trapping" effect. Here an inversion layer prevails both above and below the emission source.

II. 1. Atmospheric Dispersion Model

Several empirical dispersion models have been developed. This models, or equations are mathematical descriptions of meteorological transport and dispersion of air contaminants in an area and permit estimates of contaminant concentrations, either in the plume from an elevated or ground-level source. Among the most useful formula are those developed by Sutton, Bosanquet and Pearson, and Pasquill and Gifford. Most of the equation in use today are based on the following general equation which was suggested by Pasquill and modified by Gifford.

A quantity often needed to obtain the design parameters for use the stack and the plant operational limits and conditions for gaseous discharges is the long term Time Integrated Concentration (TIC) over one calendar year determined on the assumption that emission rate (Q) is constant. This quantity, which will be noted by ψ, may be obtained from the joint frequency distribution of wind speed, stability class an wind direction for one year. For the release of radioactive material the TIC is expressed in units of Bq s m^{-3}. In this paper, 16 sectors each of angular width θ equal to $\pi/8$ radians ($22{,}5^0$) are used. If N_{ijk} is the number of hours during the year when the wind direction is within sector i, the stability class is j and the wind speed class is k, the TIC is then given by:

$$\psi_{ijk}(x,z) = \frac{Q_0 N_{ijk}}{\sqrt{2\pi} X \theta \sigma_{zj} U_k} \{\exp[-\frac{(Z-H_{jk})^2}{2\sigma_{zj}^2}] + \exp[-\frac{(Z+H_{jk})^2}{2\sigma_{zj}^2}]\} \qquad (1)$$

where the product of X and θ is the width of sector at distance X.

U_k : wind speed class k, m s^{-1}

Q_0 : emission rate, Ci s^{-1}

H_{jk} : Effective high of stack under stability class j and wind speed speed class k, m

σ_{zj} : Vertical dispersion coefficient under stability class j, m

When only ground-level concentration is required, and the result is summed over wind speed class to give:

$$\psi_{ij}(x,0) = \frac{2Q_0}{\sqrt{2\pi} X \theta} \sum_k \frac{N_{ijk}}{\sigma_{zj} U_k} \exp(-\frac{(H_{jk})^2}{2\sigma_{zj}^2}) \qquad (2)$$

where ψ_{ij} *(X,0)* is the TIC at distance X for the effective stack high H_{jk} in the sector I under the stability class j.

Corrections are made for factors such as:

(1) Radioactive transformation

(2) Depletion due to wet deposition

(3) Correction for calm

Calculation of inhalation dose of I-131 can be applied by simple model that recommended by Clark (1979), and it is given:

$$H = C\ R\ H_{inh} \qquad (3)$$

C is annual air concentration of a nuclide in polar coordinates, at a distance X and in a sector- I (Bq m^{-3})

$$H = (TIC/Q) \,.\, Q_0 \, R \, H_{inh} \qquad (4)$$

where:

H : Effective dose equivalent, Sv/year

Q_0 : Emission rate, Bq/year

R : Mean adult annual breathing rate ≈ 8030 m^3/year.

H_{inh} : Committed effective dose equivalent from intake by inhalation, H_{inh} I-131=8.3.10^{-9} Sv/Bq

III. METHODOLOGY

III. 1. Place of research

Area of study that is used for atmospheric dispersion simulation is selected site of Ujung Lemahabang and its vicinity up to 10 km radius from release point.

III. 2. Data

The data needed for simulation are meteorology secondary data as a result of meteorological monitoring for one year duration started from August 1994 up to July 1995. Meteorological data as a simulation input cover air temperature (two elevation, 10 and 50 meter), rainfall (2 m), and wind speed and wind direction (40 m). The data are text file and each file covers one parameter and one month duration hourly data. The topographic and population data are taken from topical report of both suite topics prepared by Newjec Consultant(1996).

III. 3. Instrument of research

Instrument of research is computer program that still being developed by author. The program (software) uses Pascal Language version 7.0. It is named SERU ver 1.0. The program refers to the IAEA Safety Series 50-SG-S2. The general flow diagram for calculating Time Integrated Concentration (per Q_0) can be shown by figure 2. NPP is assumed for PWR 900 type which has stack diameter of 2 meter and high of 50 meter. The velocity of effluent release from stack is 2 m s^{-1}.

The stability conditions are divided into six classes, designated A (extremely unstable) to F (moderately stable) Methods for obtaining stability classes refer to temperature lapse rate that have been developed by pasquill (Table 1)

Table 1. Stability Class Based on Temperature Lapse Rate

ΔT/ΔZ(K/100 m)	<-1.9	-1.9 s/d - 1.7	-1.7 s/d - 1.5	-1.5 s/d - 0.5	-0.5 s/d 1.5	>1.5
Pasquill Class	A	B	C	D	E	F

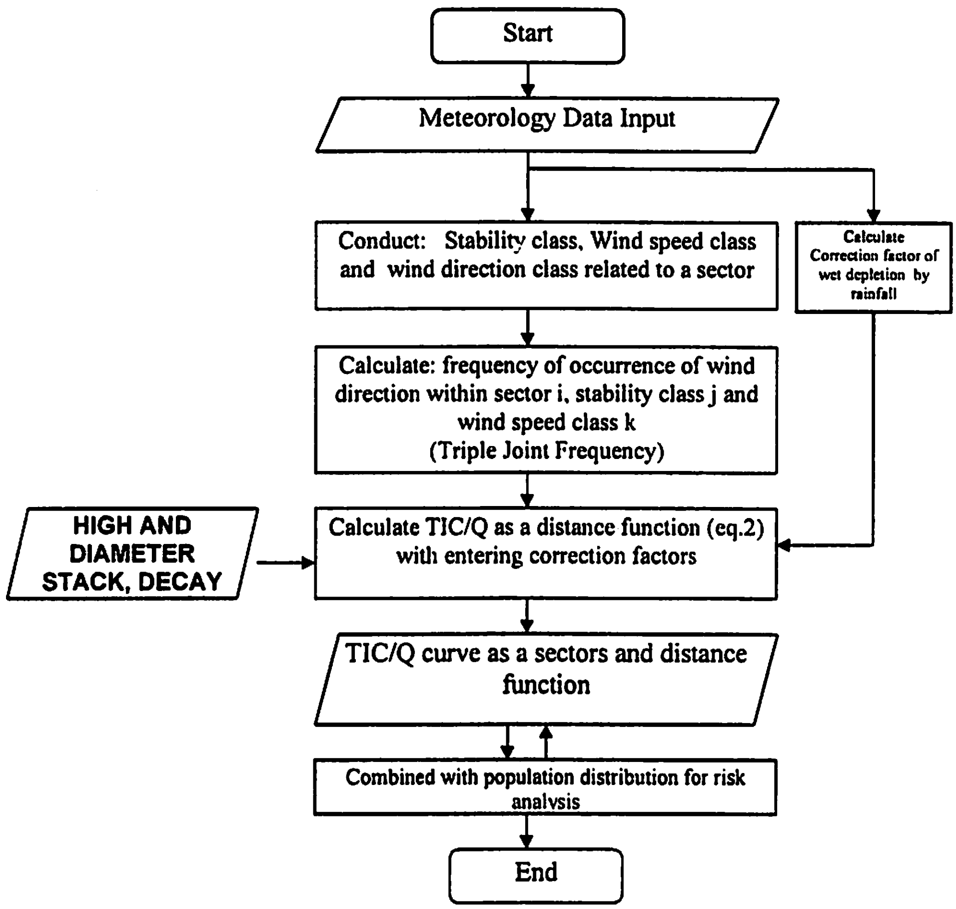

Figure 2. Flow Diagram of Atmospheric Dispersion for Routine Release

IV. RESULTS AND DISCUSSIONS

Simulation is conducted by SERU software, and the result of those simulation can be seen at figure 3 a and 3b. Dispersion pattern of radionuclides that is being released into the atmosphere around the Ujung Lemahabang site based on meteorological data during August 1994 up to July 1995. The pattern of radioactivity dispersion at Ujung Lemahabang site and its vicinity are illustrated by two-dimensional curves. The horizontal axis of curve represents distance from release point and the vertical axis represents TIC/Q value. TIC/Q increases with radii for all sectors and reaches its peak value at about 200-300 meter from release point. TIC/Q then go down and curves will reach some asymptotes. The figure is split into two (a&b) figures, one for northern direction (toward the sea) and the other for southern direction (toward the land) in accordance with the direct impact to the population.

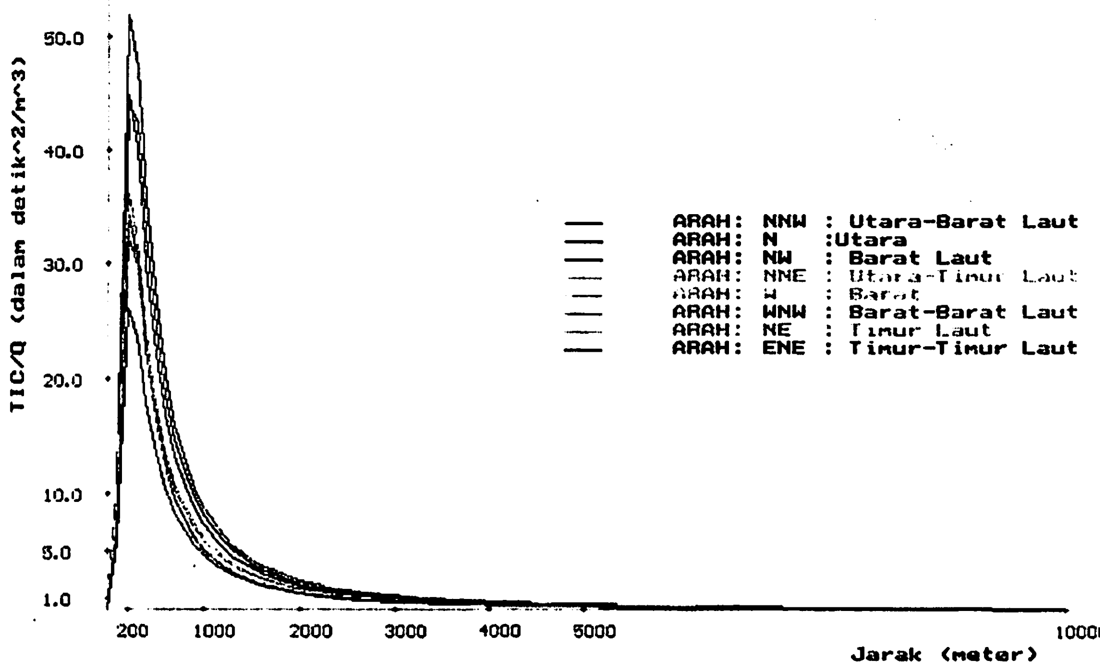

Figure 3 a. TIC/Q of I-131 as a function of distances and sectors for seaward direction (northern)

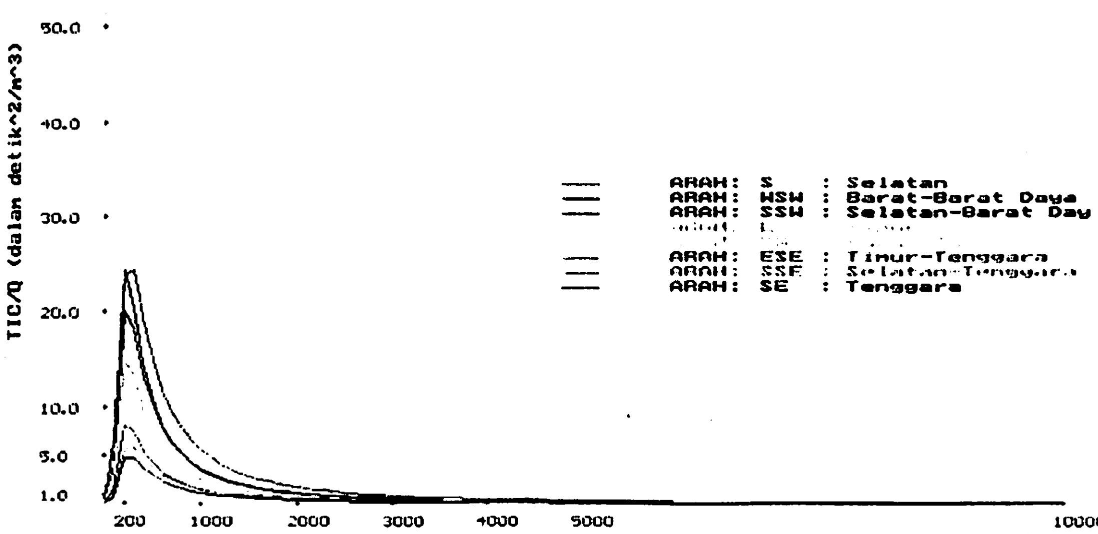

Figure 3 b. TIC/Q of I-131 as a function of distances and sectors for landward direction (southern)

The highest TIC/Q value of 52.92 s^2m^{-3} occurred at NNW sector and 200 meter radius from release point. Radioactive effluent is more dispersed to the northern sectors that are occupied by sea. This phenomena is advantageous for Ujung Lemahabang as a candidate site of Nuclear Power Plants in accordance with the population risk due to TIC/Q equivalent to the effective dose equivalent. Those dispersion pattern are more affected by distribution of wind direction as long as that one year duration. The occurrence of wind blow to the North sector (N) is 10.46%, NNW sector is 10.34%, and NE sector is 9.46%. While the occurrence of wind blow to the SE sector is 1.36%, SSE sector is 1.58% and ESE sector is 1.89%.

In 1 km radius from site there is no permanent population. Although peak value of TIC/Q is at 200 meter (within 1 km radius) but because of there is no population, therefore the risk of population due to radionuclides dispersion can be ignored. In the 1-2 km ring there are 1550 people and the highest of them occupy S sector (231), SSW (255) and SW (218). Those populations are predicted to accept the highest risk of radionuclides dispersion. TIC/Q curve combined with the population distribution can be seen at Figure 4.

Calculation of effective dose equivalent is established by assuming PWR 900 type with Q_0=3.7.10^{11} Bq/year (Newjec, 1996). The result of that calculation for any directions and distance can be shown at Table 2.

Table 2. Annual Effective Dose Equivalent of I-131 Inhalation

DIRECTION	DISTANCE (meter)	TIC/Q (s^2/m^3)	PWR 900	
			χ(Bq/m^3)	H(mSv/year)
NNW	200	51,81	0,0261017	1,74E-03
	1000	8,76	0,0044133	2,941E-04
	10000	0,0187	9,421E-06	6,279E-07
N	200	44,7	0,0225197	1,501E-03
	1000	7,29	0,0036727	2,448E-04
	10000	0,0992	4,998E-05	3,331E-06
S	300	24,4	0,0122926	8,193E-04
	1000	5,56	0,0028011	1,867E-04
	10000	0,0887	4,469E-05	2,978E-06
WSW	200	24,5	0,012343	8,227E-04
	1000	3,52	0,0017734	1,182E-04
	10000	0,0506	2,549E-05	1,699E-06

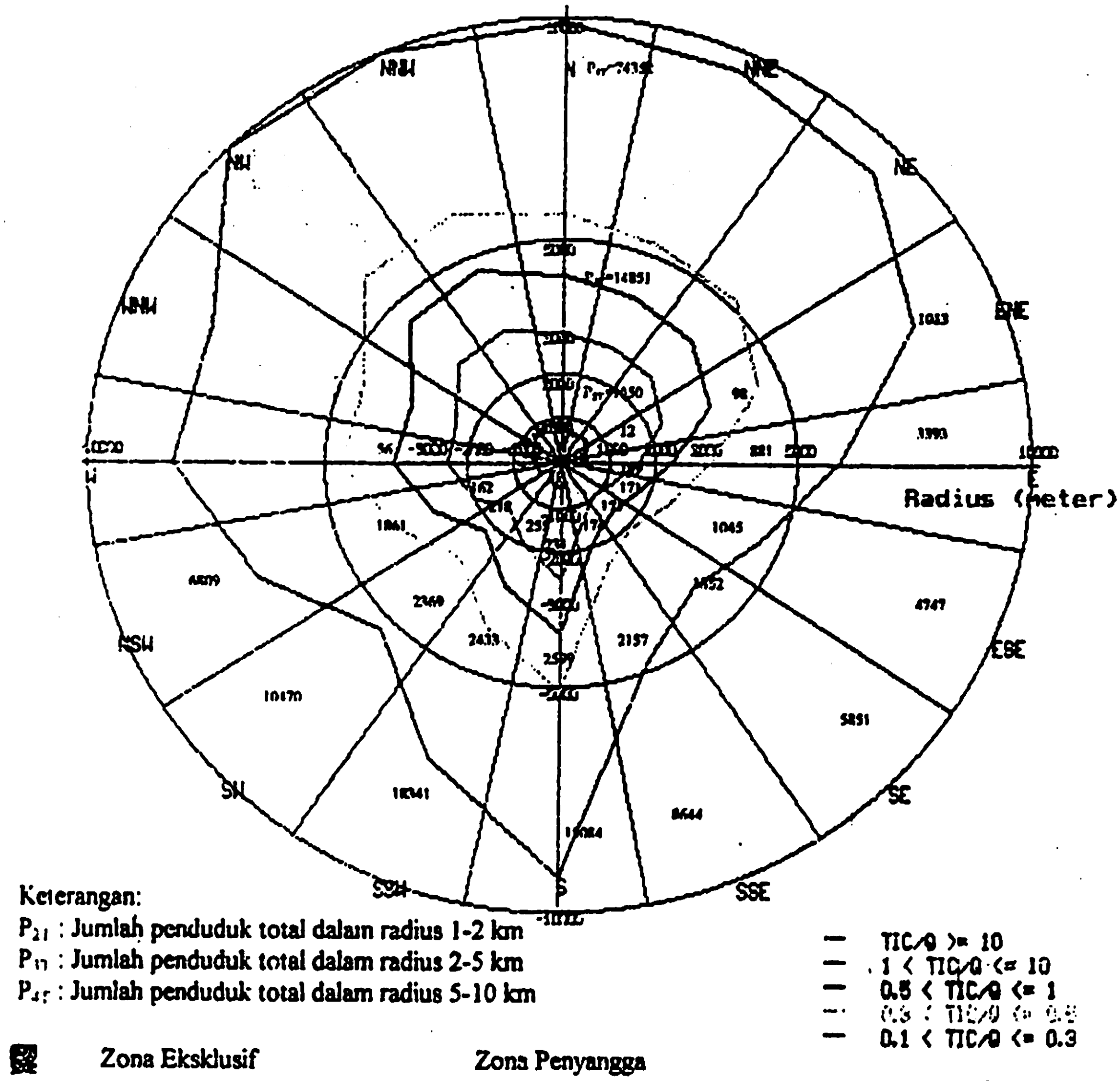

Figure 4. Profile of TIC/Q (s^2/m^3) Combined with Total Population Distribution Occupying Each Cell Around the Ujung Lemahabang Site.

V. CONCLUSION

The conclusions of the research are:

1. Concentration of radioactivity increases with increasing radius and reach maximum value at about 200-300 meters from release point and then go down asymptotically
2. Atmospheric variables significantly influence the pattern of radioactive effluent dispersion
3. The highest effective dose equivalent of direct inhalation for I-131 released by PWR 1000 is $1.7.10^{-3}$ mSv/year.

VI. REFERENCES

1. BUILTJES, PJH. 1982. Turbulent Diffusivities and Dispersion Coefficients: Application to Calm Wind Conditions. Atmospheric Pollution 1982. Proceeding of the 15th International Colloquium. May 4-7, 1982. UNESCO Building, Paris.
2. CLARK, M.J., R.H. Clarke & P.D. Grimwood. 1979. Methodology for Evaluating the Radiological Consequences of Radioactive Effluents Released in Normal Operations. Commission of the European Communities, Paris.
3. IAEA. 1980. IAEA Safety Series 50-SG-S3. Atmospheric Dispersion in Nuclear Power Plants. IAEA,Vienna.
4. IAEA. 1980. IAEA Safety Series 50-SG-S4. Site Selection and Evaluation for Nuclear Power Plants with Respect to Population Distribution. IAEA, Vienna.
5. IAEA. 1988. IAEA TECDOC450. Dose Assessments in Nuclear Power Plant Siting. IAEA, Vienna.
6. ICRP. 1990. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Pergamon Press, Oxford.
7. NEWJEC. 1996. Topical Report on Meteorology Step-3. Newjec Inc., Jakarta.
8. NEWJEC. 1996. Topical Report on Demography Step-3. Newjec Inc. , Jakarta.
9. NEWJEC. 1996. Topical Report on Dose Assessment Step-3. Newjec, Jakarta.
10. PEAVY, H.S., D.R. ROWE, & G.TCHOBANOGLOUS. 1986. Environmental Engineering. McGraw-Hill International Editions, New York.
11. SAGENDAR, J.F., J.T. GOLL & W.F. SANDUSKY. 1982. Xoqdoq Computer Program for Meteorological Evaluation of Routine Efluent Release at Nuclear Power Stations. US NRC, Washington DC.
12. TURNER, D.B.1994. Atmospheric Dispersion Estimates. Lewis Publisher, New York.